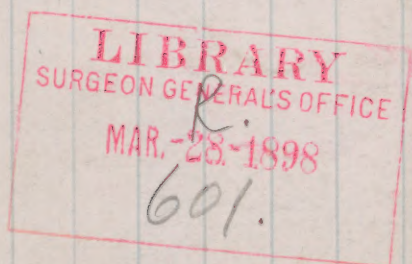


Kemp (Geo. J.)

Some observations on the
laws of muscular stimulation
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SOME OBSERVATIONS ON THE LAWS OF MUSCULAR STIMULATION AND CONTRACTION, MADE ON THE MUSCLES OF THE TERRAPIN. By GEORGE T. KEMP, Ph. D., Fellow by courtesy of the Johns Hopkins University. With Plates VII, VIII, and IX.

In spite of the fact that for the last twenty-five years the subject of nerve and muscle physiology has engaged the attention of many of the most eminent physiologists, there is scarcely a field in which more conflicting results have been obtained, or from which a richer harvest awaits improved methods of investigation. The great need is to get a nerve or muscle which will retain its normal vitality and properties for a considerable time after removal from its place in the body.

Up to the present time, by far the greatest part of the work done in this field has been carried on in Germany, on the nerves and muscles of frogs, and the readiness with which frogs' nerve and muscle undergo change has been constantly noted by those engaged in these researches.

Terrapin's muscle is a tissue which lends itself admirably to investigation, and which is in great measure free from the disadvantages attending the use of the corresponding tissue of the frog. This is especially true in the case of the neck retractors of the terrapin, which run from the skull and foremost cervical vertebræ back to the posterior dorsal and the lumbar vertebræ, thus giving a stretch of pure muscle the fibres of which are almost parallel for several inches. The attachment of these muscles is, furthermore, such as to admit of their being removed without injury to the muscle. The vitality of the terrapin's neck retractors is astonishing. I have frequently kept them working for three or four hours before they showed signs of exhaustion. In one case I worked a muscle at different intervals for seven hours, in the meantime having obtained over forty recorded curves from it, and when finally discarded it could still respond to stimuli, although its sensitiveness had diminished considerably. This makes a striking contrast when compared with the results

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of other investigators who have used the muscles (especially the thin ones) of the frog.

Aeby¹ has shown that the rate of propagation of the contraction wave may sink more than 50 per cent. in a few minutes in a thin excised muscle like the sartorius. Valentin,² to avoid this error, devised an ingenious method of working with the sartorius *in situ*, and even then found that after an hour the rate had fallen from 4.28 meters to 1.7-.7; and four and a half hours after the beginning of the experiment the rate was found to be .43 to .36 meters.

As terrapins can readily be procured in Baltimore, and as the Biological Laboratory here is equipped with many facilities for research on the physiology of nerve and muscle, I determined to test the adaptability of the terrapin's muscles to this kind of work, and began a series of experiments to find whether curarized muscle obeyed Pflüger's law for nerves. I had also intended to compare the rate of propagation of the stimulus wave in curarized muscle, as given by the wave of contraction, with the rate of propagation of the negative variation. The values of the rate of progression of the stimulus wave, as determined by these two methods, have never been found to agree to within 30 per cent. The result of the many careful experiments of Bernstein gives as a mean: Neg. variation : rate of progression :: 2.9 : 3.8 or :: 1 : 1.31, a variation of 31 per cent.

What Bernstein calls rate of progression of the contraction wave is really the rate of progression of the stimulus wave, determined by the contraction. Hence there is a variation of 31 per cent. in the same value, as determined by two different methods, which is hardly satisfactory.

The first part of the investigation I was able to accomplish successfully, but the second part I was unable to take up, as the catching of terrapins is limited by law to a certain season, and that season had expired before I was able to go on with the rheotome work. I had hoped to continue this investigation, and therefore delayed this publication, but as there is no prospect of my being able to resume this research in the near future, I

¹ Untersuch. über die Fortpflanzungsgeschwindigkeit der Reizung der quergestreiften Muskelfaser, p. 36. Braunschweig, 1862.

² Pflüger's Archiv, Vol. IV, p. 117.

publish the work as far as completed, as some results of interest have already been obtained.

METHOD OF EXPERIMENT. PREPARATION OF THE MUSCLE.

To prepare a muscle for an experiment I proceeded as follows: An opening was made in the plastron of the terrapin just over the heart. At this point there are no muscular attachments. When the piece of plastron is taken out, the heart, lying in its pericardial sac, is directly exposed. The pericardium is now cut through, and the tip of the ventricles not too tightly held by a pair of forceps, while the needle of a fine hypodermic syringe is pushed through the ventricular wall slightly to one side of the apex, and from 8 to 10 minims of a one per cent. solution of curare in .75 per cent. solution of NaCl is injected directly into the ventricle. It is necessary to inject the curare directly into the circulation, for absorption is so slow in the terrapin that three times the amount of curare mentioned, when injected subcutaneously, has little or no effect even after eight hours.

When properly done the needle of the syringe may be pushed through the wall of the ventricle without the loss of more than a drop or two of blood. To accomplish this, it is best, after injecting the curare, to retain the apex of the ventricle between the forceps while the heart is making three or four beats, and then release it at the end of systole.

Within 20-30 minutes the animal is completely under the influence of the curare. To assure myself of this I did not rely on the pinching reflex, but isolated a nerve on the back of the thigh and stimulated it with a tolerably strong interrupted current. When the muscles of the leg no longer responded to this stimulus I knew that the animal was completely under the influence of the drug. Meanwhile the animal was pithed and its brain destroyed. The cerebral cavity was stuffed with cotton to prevent hemorrhage. The plastron was now removed and the skin cut loose from the carapace, along its whole line of insertion posterior to the bridge joining the plastron to the carapace. The symphysis pubis was next divided, and the attachment of the pelvis to the carapace broken by running a carpenter's gouge along the median line of the carapace. The precoracoidal symphysis was next cut, together with the plate of cartilage uniting the scapulæ,

and the two halves of the shoulder girdle were forced apart as far as possible.

If now the hind legs be drawn firmly and steadily forward they will carry with them the pelvis and peritoneum with its enclosed viscera, and leave the large neck retractors exposed.

The neck retractors are not single muscles, but are composed of several groups which are attached to the sides of the bodies of the vertebræ, in the cervical region anteriorly, and in the lower dorsal and lumbar regions posteriorly. As many of the groups as desired may be used. The best way to separate the muscles from their posterior attachments is to split the vertebræ along the median line with an arthrotome, and then, with a carpenter's gouge, to dig out a piece of the carapace with which are united the pieces of vertebræ to which the muscle is attached. As the cervical vertebræ are not fused with the carapace it is only necessary to split them and separate them with a scalpel from all attachments.

One prominent group of muscles belonging to the neck retractors is attached to the skull by a ligament which can be traced as far forward as the palatine bones, but the tendon of this group can easily be detached from its connections. When it is advisable to use only one group of the retractor muscles, this is the best adapted for the purpose.

By following carefully these methods there results little or no injury to the fibres. The greatest chance for injury comes in while splitting the vertebræ and severing their connections with adjacent parts, but after some practice this can be accomplished in a very few minutes; one end of the muscle being bathed in the natural exudation from the tissues, and kept from drying by being covered with viscera and peritoneum, while the other end is being operated on. The danger of producing changes in the muscle by subjecting it to abnormal conditions is thus reduced to a minimum. Care must also be taken to leave slightly more bone at each end than that to which the muscle is attached, in order that a string may be tied to it without injuring the fibres.

Part of the apparatus employed was a modification of that used by Bernstein,¹ in his work on the rate of propagation of the

¹ Untersuchungen über den Erregungsvorgang im Nerven und Muskelsysteme. Heidelberg, 1871.

wave of contraction in muscle; the rest is an arrangement of my own.

The muscle was placed in the moist chamber (Fig. 1, *A*) on a glass plate (Fig. 1, *B*), across which platinum wires were stretched at known distances apart, and so arranged that any one of them could be made the anode or cathode respectively for any given stimulus. A piece of strong thread was tied to the fragment of bone at each end of the muscle. One thread was fastened firmly, while the other passed through a hole in the bottom of the moist chamber and suspended the weight by which the muscle was stretched. On the muscle, near one end of the plate, was laid a narrow strip of glass (Fig. 1, *s*), drawn out to a thinness just sufficient to make it raise the weight of the recording lever without bending and so causing its own elasticity to influence the curve. This strip was kept in position by four pins (Fig. 1, *p*, *p'*, *p''*, *p'''*). To each end of the strip was fastened a piece of silk; the two pieces were passed through a large hole in the bottom of the moist chamber and brought together below, thus making an inverted stirrup, of which the glass strip was the base. From where the strings were joined below a single piece of silk ran down to support a small ebonite pulley (Fig. 1, *P*), over which passed a piece of silk, connected at one end with the recording lever, while at the other it wound on the axis of a screw (*s'*) by which it could be wound up or let out and the recording lever raised or lowered accordingly.

This arrangement of the pulley is the same as that used by Bernstein. It is very convenient, as it doubles the lift of the lever and admits of easy adjustment.

One objection that has been urged against the apparatus of different observers is, that a considerable mass would have to be set in motion before the curve began to be recorded, and the momentum of this mass would tend to prolong and alter the true curve.

To obviate this is of great importance, and the apparatus employed was arranged with special regard to this point.

To a Foster's adjustable lever attachment (Fig. 1, *F*) was fastened a common straw, making the whole length of the lever about 25 centimeters. To the end of the straw was fitted a cap of writing paper, to which a piece of extremely thin aluminium

foil was soldered by a thin film of sealing wax. This piece of foil was trimmed to a point which recorded the curve.

I cannot speak too highly of aluminium foil for this purpose. When of the right thickness it has just the proper spring to keep the point sufficiently pressed against the plate of the myograph, and at the same time it yields to greater pressure and thus obviates all risk of putting the lever out of adjustment.

Later in my experiments I made the following improvement in the writing point (Fig. 1, *T*). Instead of trimming the foil down to a point for recording on the plate, I took part of a fine sewing needle, and, after running it twice through the foil, I fastened it firmly in position by a thin film of sealing wax. By this arrangement the elasticity of the aluminium was retained, while the point of the needle insured a more delicate line than could always be gotten with the foil point.

An improved Fick myograph (see *Journ. of Physiol.*, Vol. II, p. 164) was used for recording the curves. The time was given by a tuning fork making 200 vibrations to the second. Some of the curves were taken on smoked gelatinized paper, and the tracings set with a solution of shellac in alcohol. The other curves were taken directly on the smoked glass plate, set with turpentine, and photographed as blue prints.

It will be observed that the arrangement which I have employed necessitates the passage of the current in the longitudinal direction through the muscle. This was done intentionally, for the results of previous work by different observers, though conflicting, in general go to show that a greater contraction can be obtained from the same strength of current when passing longitudinally through the muscle than when taking any other path. Furthermore, under these conditions diffusion of the current is at a minimum.

Unless otherwise specified, the closing current is to be understood as having been used. Direct currents were used in preference to induced, for Brücke¹ has shown that curarized muscles, like muscles in certain pathological conditions, are more sensitive to the stimulus of direct than of induced currents.

The first question that I undertook to decide was, whether curarized muscle obeys Pflüger's law for the stimulation of nerves;

¹ Sitzungsberichte d. Wiener Akademie, 1867 and 1868.

that is, does the stimulus start from only one electrode, viz., the cathode on closing, and the anode on opening the current.

Of previous investigators who have taken up this question, von Bezold¹ and Engelmann² answer the question in the affirmative, while Aeby³ and Bernstein⁴ take the opposite view. Aeby⁵ admits that the stimulus at the cathode is stronger, but denies that it arises there sooner than at the anode. Bernstein⁶ asserts most positively that the muscle is stimulated at both anode and cathode, and that the stimuli are equal and simultaneous. In my experiments the muscle was essentially in the same position as in the experiments of Bernstein, and my results are of interest when taken in connection with his.

I find that *when the muscle is moderately weighted it will obey Pflüger's law, but when the weight is so small that its resistance to the contraction of the muscle is insignificant, it apparently does not obey this law, but acts as described by Bernstein.*⁷

In one experiment where the muscle was not weighted at all, one electrode was 1.5 mm. from the section of muscle on which the glass strip was laid, while the other was 70 mm. distant. No difference could be detected in the length of the respective latent periods of the contraction waves when the polarity of the electrodes was reversed, although, according to Pflüger's law for nerves, the stimulus would have to travel *nearly fifty times farther* when the cathode was at the distant electrode than when it was at the one near the recording section.

This is shown in curve 1. When this curve was taken the muscle was slightly weighted, but not enough to offer any appre-

¹ Untersuchungen über die Elektrische Erregung der Nerven und Muskeln. Leipzig, 1861.

² Pflüger's Archiv, Vol. III.

³ Untersuch., &c., op. cit.

⁴ Op. cit.

⁵ Op. cit., p. 58.

⁶ Op. cit., pp. 81, 82.

⁷ This apparent difference is probably due to the fact that, when the muscle is unweighted, the stimulus produces a regular contraction which starts from the cathode but which causes the whole muscle to jerk. When the muscle is stretched by a considerable weight this is prevented, and we have recorded only the true wave of contraction as it proceeds along the fibre. Bernstein worked with the adductor of the frog's thigh and used no stretching weight.

ciable resistance to the contraction. One curve appears to have a longer latent period than the others ; this is due to the fact that it is recorded slightly above the base line. If, by the eye, it be lowered to the base line, it will be seen that its latent period is about the same as that of the other two. The letters *R* and *L* denote the position of the reversing key to right or left, and consequently show opposite polarities of the electrodes. The two *R*'s are simply for control.

Curve 2 shows the effect of loading with a weight sufficient to keep the muscle well stretched. On the same base line two curves are taken, the polarity of the electrodes in one curve being the reverse of that in the other. *The curve with the shortest latent period is always obtained when the cathode is nearest the recording section of the muscle.* The difference between the latent periods of the two curves depends upon the distance between the electrodes, but it is extremely interesting to notice that the two do not vary in the same ratio, but in such a way as would make it appear that the rate of propagation diminished as the stimulus proceeded along the fibre. This point is suggestive and needs further investigation, and I hoped to publish something more definite upon it had I been able to complete the research.

While working up this subject I also repeated the experiment of von Bezold, which was repeated later by Engelmann, both of whom obtained the same result. Bezold's method was to clamp the muscle firmly enough to prevent a contraction wave from passing the clamp, but not so tightly as to destroy the conductivity of the fibres. The electrodes were so placed that the clamp came between them.

In Fig. 2 may be seen my arrangement of the apparatus for this experiment. If the muscle obeys Pflüger's law we should get a longer latent period to the curve when the cathode is at *e* than when at *e'*, for the contraction of the segment of muscle above the clamp *C* only serves to raise the weight *X*, and does not affect the recording lever ; hence there would be no contraction recorded until the stimulus had traversed the length of muscle from *e* to *C*. If the stimulus starts from the anode as well as from the cathode, the latent period in each case should be the same ; for the moment the segment below begins to contract, the lever will begin to write the curve.

The results of this experiment may be seen in curve 5. The sign of the curves on the plate is the same as the polarity of the electrode below the clamp when that particular curve was taken. Curve 5 consists of five curves. The numbers at the respective curves show the order in which they were taken. When the first curve (+1) was taken there was defective contact at one part of the circuit, and hence the curve is worthless. The trouble was removed before the other curves were taken. The two + curves and the two — curves corroborate each other. The difference between the curves is striking. The curves marked minus (—) may be taken as the normal curve of the muscle when stimulated directly on the part which records the contraction. In the curves marked plus (+) we see that not only is the latent period prolonged by the length of time it takes for the stimulus to pass from *e* to below *C*, but *the whole character of the curve is altered*.

Bernstein has pointed out that the wave of contraction is diminished in intensity as it proceeds along the fibre, and this observation is confirmed by the diminished height of the curves marked + in curve 5, as compared with those marked minus.

The curves show also another interesting point which, so far as I know, has not been mentioned before, viz., that the curve length or *duration of the contraction* is apparently *increased* as the wave travels along the fibre. This point receives additional confirmation when we examine the curves on curve 3. Here the difference in *wave length* is not so marked as in curve 5, for the electrode *e* was just above the clamp, while in the former case it was considerably above. Bearing this in mind, it is interesting to notice that there is a considerable difference in the height of the curves. This would tend to show that the resistance of the muscle within the clamp is greater than in the remaining portion. It is therefore questionable whether it is advisable to employ this method in measurements involving time, such as determining the *rate of propagation of the contraction wave, etc.*

Another point which I have observed in confirmation of previous observers, supporting the assumption that curarized muscle as well as nerve obeys Pflüger's law, is, that if a very much exhausted muscle be stimulated by a minimal current, a single twitch may be seen at the cathode, while no change is noticed at the anode. This may be explained by the view of Aeby, viz.,

that a stimulus also takes place at the anode but is too weak to cause a contraction.

In determining the rate of propagation of the stimulus from the contraction, the apparatus described in my first experiment was used. All the wires (seven) on the glass plate (Fig. 1, *B*) were connected with the binding screws (*b*¹–*b*⁷) of the moist chamber, so that the muscle could be stimulated at seven different places without disturbing it after it had once been placed in position. In applying the stimulus the cathode was always kept nearest the recording section of the muscle, so that no complications from an electrotonus could arise. The muscle was stimulated at different known distances from the recording section, the distance in some cases being equal to zero.

In the latter case the interval between the stimulation and the contraction represents simply the latent period of the muscle, while the corresponding interval in the other cases will depend upon the distance of the cathode from the recording section. From a comparison of the intervals of the different curves the rate of propagation of the stimulus can be determined.

From the work as far as completed I can only say that the rate may be given roughly as from 2–3 meters per second. There are great variations between the muscles of different terrapins, a fact pointed out by all previous investigators. The terrapin's muscle is more sluggish than the muscles of the frog, hence the above value is not far from what we should expect when compared with the rate as found by Bernstein and Valentin for frog's muscle, viz., 3–4 meters per second.

The other results of interest obtained from my work may be briefly stated as follows :

The height of the curve depends on the strength of the stimulus, but the latent period does not. The strength of the current was varied by a resistance box, and a galvanometer was interpolated in the circuit as an index to the strength of the current employed.

When the order of polarities at a given electrode is +, –, +, –, etc., for successive stimuli, the corresponding curves are higher than when the order is +, +, +, etc., or –, –, –, etc. This confirms a statement made by Hermann,¹ that the passage of a constant current through a muscle increases its irritability for

¹ Hermann's Handbuch der Physiologie, Vol. I, p. 95.

the closing of currents in the opposite direction, or for the opening of currents in the same direction. Compare the curves +1 and +2 on curve 3. The curve +2 is lower than +1 because it was taken immediately after it and the current passed through the muscle in the same direction.

I have also noticed, as have previous observers, that when the current is sent into a muscle, it frequently relaxes before contracting. This is shown in curve 4, by a sinking of the curve below the base line. This phenomenon seems to have some connection with the stretching weight of the muscle, as it is not perceptible unless the muscle is well weighted; it is the more marked the heavier the weight.

From this it would appear as though the muscle was normally in a state of slight tonus which was for the moment destroyed when the stimulus was sent in, thus allowing the muscle to be more stretched by the weight.

These are the prominent results of my research, which I must now give in an uncompleted form, hoping that they may be of value to some subsequent observer who may undertake investigations in this field.

In conclusion, I would express my thanks to Professor Martin for every courtesy shown me while in his laboratory, as also for many suggestions which were of material aid to me in the prosecution of this work.

DESCRIPTION OF THE FIGURES.

FIG. 1.—Arrangement of apparatus in experiment for determining the rate of propagation of stimulus wave as given by the contraction, and also for ascertaining whether curarized muscle obeys Pflüger's law for the stimulation of nerves.

A. Moist chamber, with a large hole in the bottom, shown just below the letter *M* in the figure.

U. Upright which supports the moist chamber.

D. Heavy iron base into which the upright *U* is screwed.

b'-b''. Binding screws to the moist chamber. These were connected with the electrodes of the plate *B*, and with the battery as shown in Plate 3.

B and *B'*. Glass plate on which the muscle was laid. It consists of a piece of window-glass 125 cm. in length by 3 cm. in width.

Along its long edge on each side was cemented a narrow strip of glass, best shown in B'' , which represents a section of B' taken at the electrode e^2 .

The electrodes were platinum wires, soldered with sealing wax to the strip a and stretching across to the corresponding strip on the opposite side. They are seen at $e^1, e^2, \dots, e^7$ in B' , and in B'' are represented by the dotted line, which shows their position when bent over the muscle so as to make good contact both above and below.

Between the electrodes and the glass plate beneath is slipped a strip of glass, cut to the proper width and not quite as thick as the strips a and a' in B'' .

This arrangement possesses a double advantage. In the first place the strip can easily be removed and thoroughly cleaned after each experiment; and secondly, we may be assured of better contact, when the strip does not come quite up to the electrodes, than if the latter were stretched directly across the flat surface of a glass plate.

p^1-p^1 . Four pins, soldered to the strips a and a' with sealing wax. Their purpose is to guide the glass strip S as it is raised by the contraction of the muscle, and to keep it from slipping from its position.

S . A narrow strip of thin glass which rests on the muscle.

$s-s'$. Pieces of silk thread, soldered to the ends of the glass strip S with sealing wax. These run down to k , the point where they unite, and are fastened to the silk thread which suspends the pulley P .

P . A pulley over which passes a silk thread fastened at one end to L , the recording lever, while the other winds around the screw S' , by means of which the lever can be quickly and accurately adjusted to any position in the vertical plane.

G . A glass rod drawn out and bent as shown in the figure. It is so placed as to keep the thread from touching any part of the lever or its adjustable attachment F .

T . Tip to the recording lever L . It consists of a piece of aluminium foil, with a needle stuck through it and fastened rigidly with sealing wax.

$M-M'$. The muscle in position on the plate. The thread from the end M of the muscle is passed through the hole h' , and made fast to a hook not shown in the figure. The cord from the end M' passes through the hole h and suspends the stretching weight, X , of the muscle.

FIG. 2.—Description of apparatus used in repeating Bezold's experiment.

A. Moist chamber as in Fig. 1.

M, M'. Muscle. (In this experiment only one group of the muscles making up the retractor was used.)

H, H. Horizontal arms supporting a glass tube over which, as over a pulley, was passed, from the muscle, the string *J* which suspended the weight *X*.

H'. Horizontal arm supporting the clamp *C*.

C. Clamp, made from an adjustable burette clamp, and lined with sheet rubber in order that the current might not be conducted by the metal.

J. String from end of muscle to weight *X*.

X. Weight which could be raised freely by the contraction of *M'*.

J'. Piece of silk running from tendon of muscle directly to the recording lever *L*. The lift in this case was so great that the pulley was dispensed with.

L. Recording lever, made from a thin strip of light wood, about half the length of the lever in Fig. 1.

F. Foster's adjustable lever attachment as in Fig. 1.

W. Reversing key, or wippe, by which the polarity of the electrodes could be changed.

Cu. Copper; *Zn.* Zinc of battery.

e, e'. Electrodes on muscle. These were made of platinum wire, and made to encircle the muscle.

FIG. 3.—The electrical connections used with the apparatus in Fig. 1.

K¹. Universal connecting key, by which any one of the binding screws of the chamber *A* may be made the positive or negative pole at will.

It consists of an ebonite plate, to which are screwed seven isolated plates of brass, each having a semicircular excavation at both ends, parallel to the line of the ends of these plates. On each side of the block are screwed the brass strips *N* and *N'*, with excavations in them opposite those of the plates. These strips are not in contact with the plates, but the plates and strips may be connected by a brass plug which fits into the circular hole made by the excavation in each. Each of the plates is connected with one of the electrodes of the moist chamber. This connection was made by wires insulated with silk of different colors, so as to avoid confusion. The brass strip *N* was connected with *R'* directly; the strip *N'* was connected with *R* by the path *N', K¹, K², R*.

R, R'. Two binding posts connected by a tongue of brass which is knocked away by the myograph in its swing. The posts *R* and *R'* are connected with the poles of the battery, so that when the tongue is up, and *R* and *R'* connected as represented by the dotted line, we have the primary circuit: *Cu, K³, W, R', R, W, Zn*. Into this circuit is inserted a Du Bois Reymond key, *K²*, for convenience in breaking the circuit, and also a reversing key, *W*, by which the direction of the current may be changed.

If *R* and *R'* had no connections except with the battery, it is clear that when the circuit is broken between them they become the positive and negative poles respectively. Since *R* and *R'* are connected with the strips *N'* and *N* respectively, it follows that these must become the positive and negative poles when the connection is broken between *R* and *R'*. In the same way, by connecting the strip *N* or *N'* with one of the brass plates between them, we confer its polarity to that plate, and thence to the binding screw of the moist chamber with which the plate is connected, and thence, in turn, to the electrode on the muscle. As any one of the brass plates may be connected with either of the strips *N* or *N'* at will, it follows that we may make any one of the electrodes the cathode or the anode at pleasure.

When everything is ready to record a curve, the tongue between *R* and *R'* is in position, closing the circuit *Cu, K³, W, R', R, W, Zn*. As the myograph swings the tongue is knocked away, the connection between *R'* and *R* is broken, and the current takes the longer circuit *Cu, K³, W, R', N*, through the plug to one of the brass strips, thence to the moist chamber, returning through another wire to its corresponding plate, thence through a plug to *N', K¹, K², R, W, Zn*.

K¹. A Du Bois Reymond key for opening or closing the secondary circuit.

K². Key for throwing the galvanometer *G* in or out of the circuit.

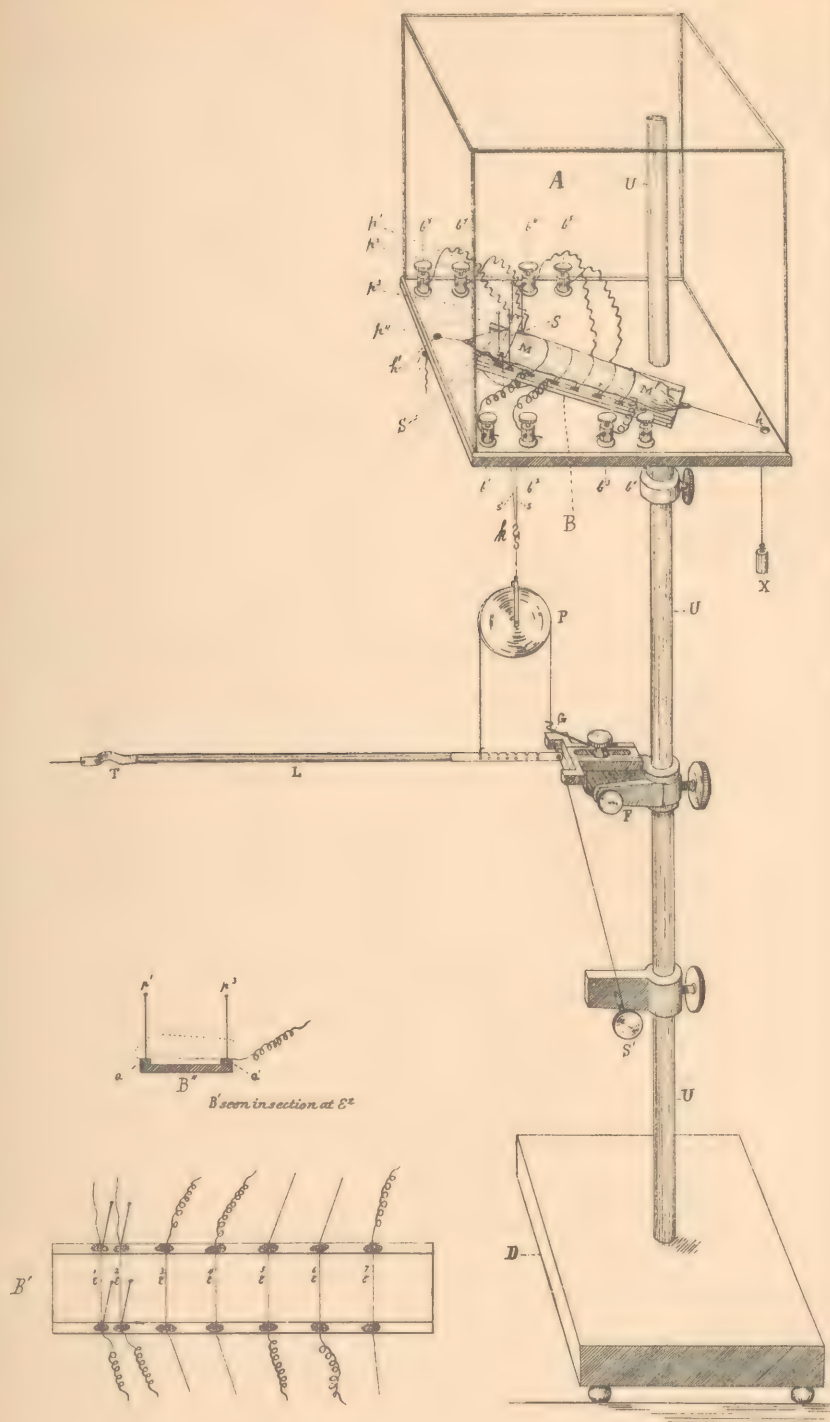


Fig. 1

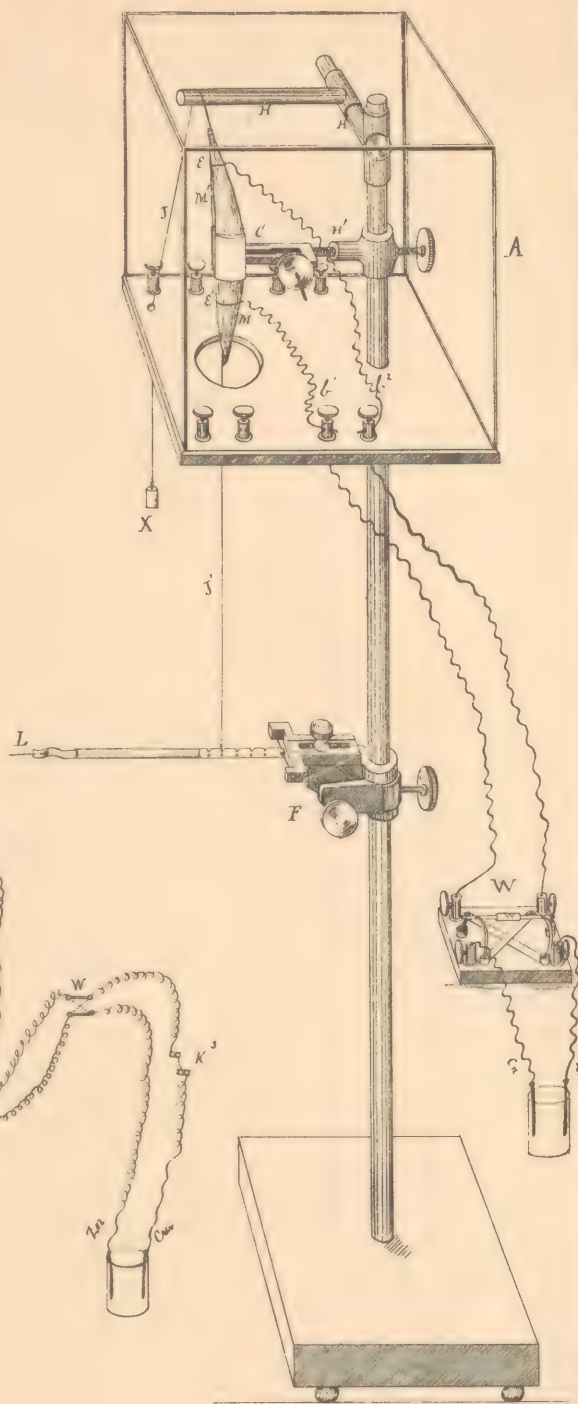


Fig 2

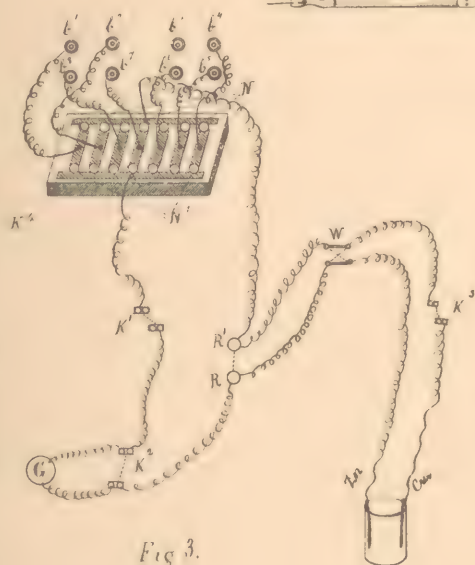
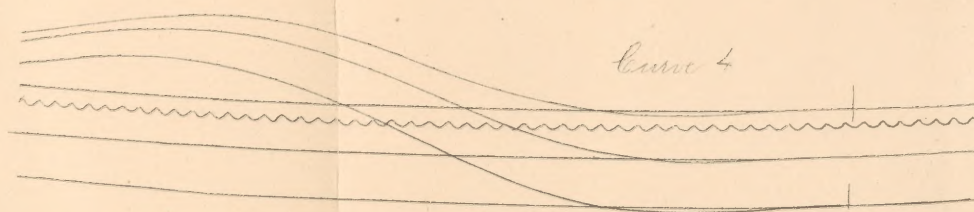
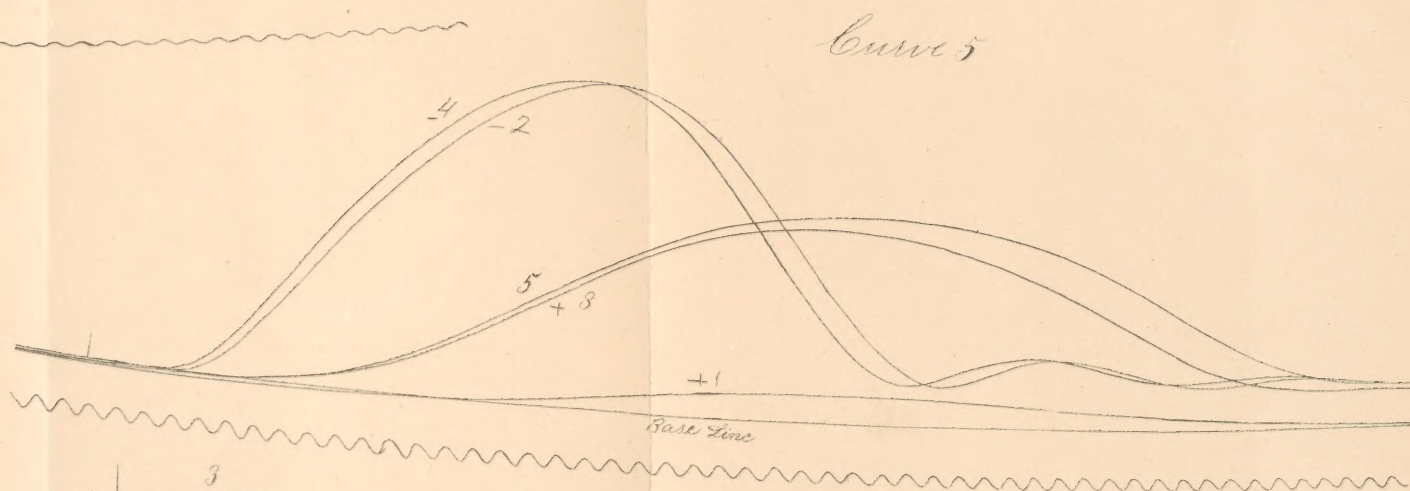
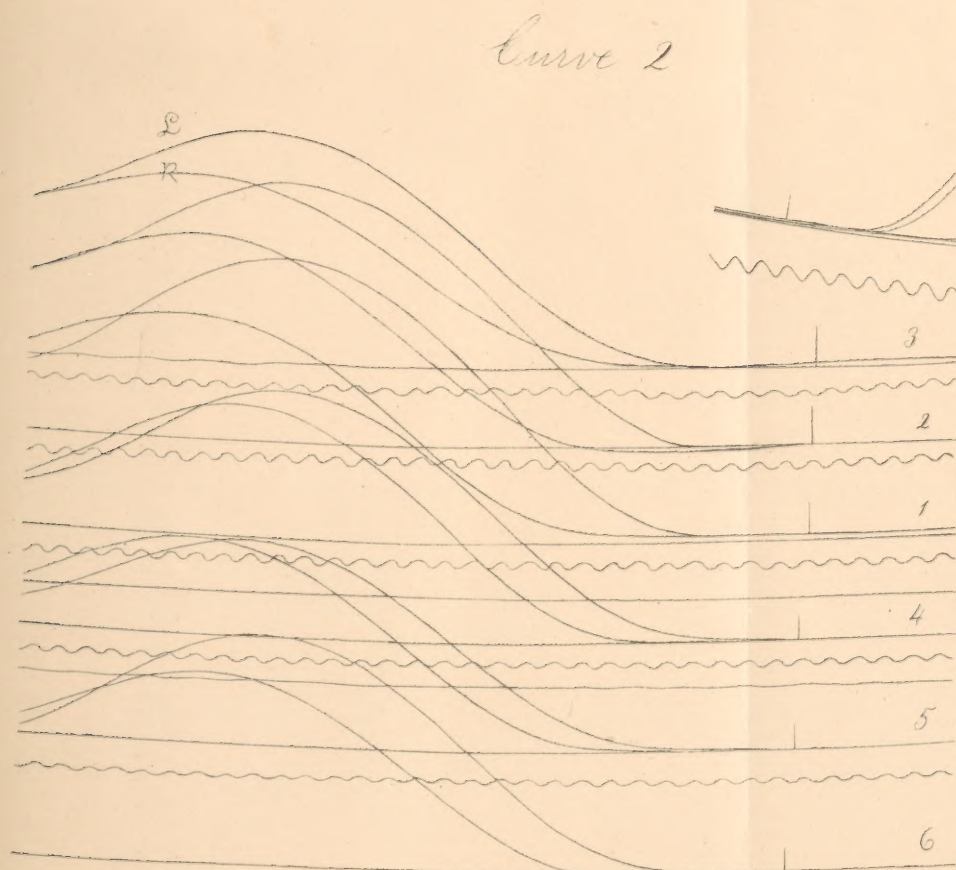
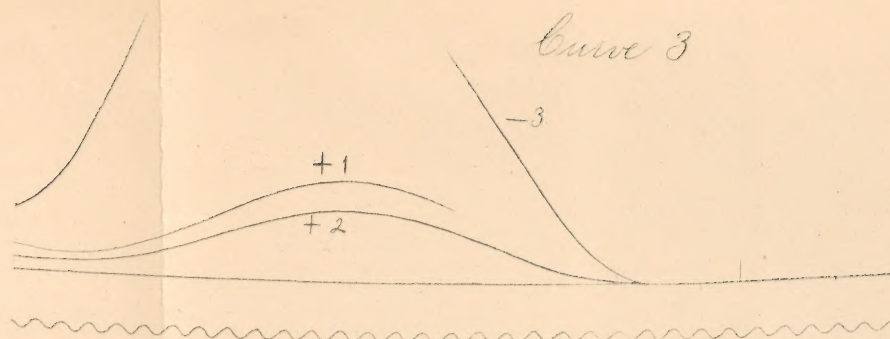
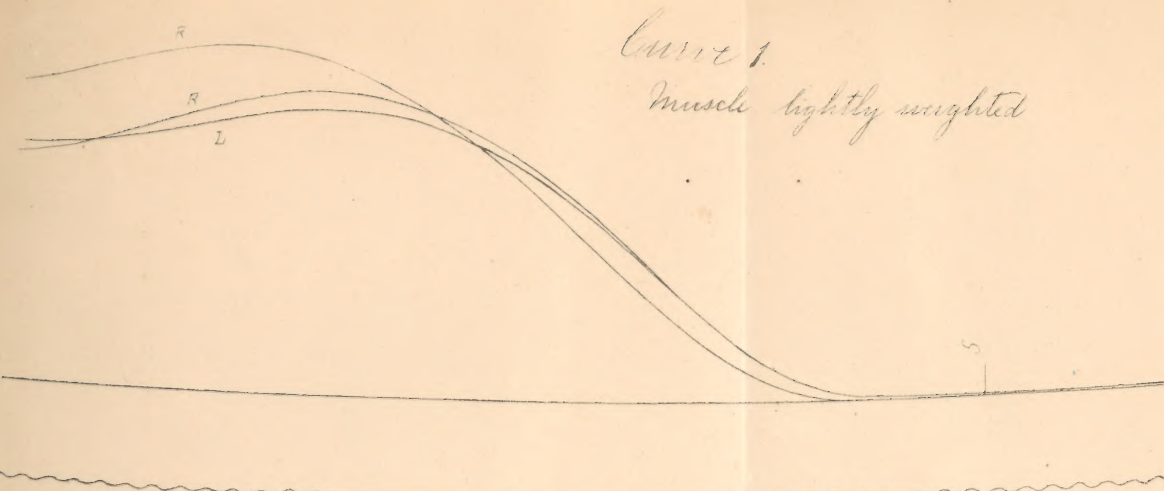


Fig 3.



x Dec 15th Jan'y 1881
W. Chandler

x Dec 25th Jan'y 1881
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Ed Chambers